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SECTION OF GEOLOGY AND MINERALOGY

OCTOBER 6, 1941

PROFESSORS J. T. STARK, W. E. POWERS, and A. L. HOWLAND, Department of Geology, Northwestern University; PROFESSOR J. HARLAN JOHNSON, Department of Geology, Colorado School of Mines; PROFESSOR C. H. BEHRE, JR., Department of Geology, Columbia University; and PROFESSOR DON B. GOULD, Department of Geology, Colorado College: *The Geologic History of South Park Colorado.* (This lecture was illustrated by lantern slides and was presented by Professor Behre).

South Park is a great depression in central Colorado. Though lying at an altitude of about 9,000 feet, it is almost surrounded by high ranges of the southern Rocky Mountains, some of which rise to altitudes of more than fourteen thousand feet. In sharp contrast with these towering peaks, the Park is characterized, especially, by its remarkably even surface. Its relatively barren floor is marked by several almost flat sub-levels, in places greatly dissected and isolated, but elsewhere rising in successive steps and thus suggesting wave-cut benches, pediments, or stream terraces. Locally, there are also hogback ridges, reflecting monoclinal dips

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of resistant beds. The marginal wall of high mountains is broken only to the south. Here, a low divide of a few hundred feet separates the Park surface from the Arkansas Valley. Despite this breach in the encircling ranges, the two streams draining the Park, the South Platte and the Tarryall rise in the mountains that form the western wall and flow eastward across the Park and across the Front Range; thus suggesting a history of superposition or antecedence.

In brief, the generalized picture conveyed at first glance is one of a fault graben or of an old lake bed, with some complications in structure and in detailed physiographic history. On the floor of the Park and the bordering elevations, numerous erosion levels are believed to have been recognized, but no detailed study has been devoted to the geologic history of the unusual depression represented by the Park itself.

As a result of three seasons of field work, a far more complex development of South Park than that implied above has been reconstructed. The facts, upon which such a history is based, are not only physiographic but structural, stratigraphic, and petrographic as well. It has proved possible to determine the age of structural features of earlier origin in the usual manner, by reference to the stratigraphic succession, which ranges from pre-Cambrian to Pleistocene, the Silurian being the only period unrepresented by sediments. Particularly helpful has been the finding of vertebrate fossils at several horizons. These have enabled a dating of physiographic events far more exactly than hitherto for this region.

Though the earlier history is interesting, it will not be set forth here. The episodes which contributed most significantly to the present form of the Park began with the Laramide revolution. This was initiated by an uplift to the west, leading to erosion of pre-Cambrian and younger rocks and to the deposition, mainly by eastward flowing waters, of at least 7,000 feet of Denver (Paleocene) beds. Later came the Elkhorn fault, first recognized in 1910 by Washburne. This crowded pre-Cambrian crystalline rocks westward over the Denver sands and gravels. The Elkhorn

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is a low-angle thrust that has been traced for 36 miles along the eastern edge of the Park. It is one of the major displacements of the southern Rocky Mountains. Three other large reverse faults cross the Park in a northwest direction. Their throws are of the order of 500–1000 feet, but they obviously cross the "grain" of the topography and had little to do with the present form of the Park. Despite careful search for larger displacements and despite the presence of many minor normal faults, there is no evidence that the topographic basin of the Park is to be assigned to simple graben faulting. Its present form, however, was certainly outlined during the Laramide revolution by two structural features: (1) the monocline of resistant Paleozoic beds which makes up the eastern slopes of the ranges west of the Park; and (2) the escarpment, now largely a fault line scarp, of the Elkhorn thrust, east of the Park.

Some time after the Laramide revolution, the structural basin was etched out into a broad river valley. The Tertiary history of this basin included lacustrine deposition; vulcanism, especially in the south, yielding tuffs and flows; and some later folding and faulting. The earlier lavas apparently acted as ponding agents, causing lake deposits to form in the Oligocene and early Miocene. The later Tertiary sediments were chiefly fanglomerates or river alluvium, however, and were still being deposited during the Miocene and possibly early Pliocene. These youngest beds dip in the direction of the former southward course of the stream that drained the Park into the Arkansas. The last effects of the South Park river were of Pliocene age, a remarkable strath which truncates the alluvial strata underlying the low, hilly divide that constitutes the southern boundary of the Park. These truncated beds contain vertebrate remains of the early Pliocene or late Miocene. Subsequently, there seems to have been tilting *downward* to the north, which favored the headward capture of the southward Park drainage by streams whose growth was across the Front Range. The reasons for this piracy are still not wholly clear and must await detailed studies farther to the east, for the geology of the Park itself sheds no light upon this question.

After the drainage diversion came some alluviation, probably coupled with glaciation. Two stages of late glaciation are clearly recorded by as many sets of moraines and terraces, and three earlier glacial stages are suggested by a corresponding number of higher alluvial terraces. These glacio-fluvial (?) terraces constitute the five conspicuous sets of flats recognizable within the Park. All are below the level of the divide at its southern margin. Thus, glaciation had no effect on the fundamental problem of the origin of the Park as a whole, but it greatly modified the detailed topography.

In brief, then, the Park was first outlined by the Elkhorn fault on the east and the eastward dipping monocline on the west. The basin, thus formed, was etched out by stream work, was, in part, the site of lakes, and was, variously, modified by vulcanism. Later the main, southward flowing river was beheaded by one or more streams having an eastward gradient. There are no simple erosion levels in the Park at elevations less than 12,000 feet, except that crossing the southern divide. Contrary to statements by earlier investigators, this is younger than the upper Miocene at earliest, since it bevels rocks of that age. The general form of the Park, today, thus bears traces of its original Laramide structure, of its pre-Pliocene stream erosion, of Pliocene tilting and headward trenching by east-flowing streams, and, finally, of its Pleistocene alluviation and glaciation. However simple this history may appear at first sight, it proves to be highly complex when the facts are more carefully examined.

These studies were made possible by a grant from the Penrose fund of the Geological Society of America and by a research grant from Northwestern University. The authors wish to express their appreciation for these financial aids and for permission given by the Geological Society of America to publish this preliminary description of a part of their work.

SECTION OF BIOLOGY

October 14, 1941

Professor Otto Glaser, Amherst College, Amherst, Mass.: *Pattern and Growth.* (This lecture was illustrated by lantern slides, patterns, stagger-patterns, and models.)

I

What symptoms of pattern can we expect in a growing organism? The answer is not entirely simple. Were we confronted with an isolated and unlabelled egg 100 microns in diameter, we should require the services of a particularly specialized specialist to tell us what sort it might be. After the egg had undergone numerous divisions and the resulting mass had increased sufficiently in size, less specialized specialists would be able to hazard a guess. However, only after further growth and transformation would the general nature of our creature become an open secret in biological circles. All of us would then recognize the basic pattern of a vertebrate. Subsequently, even a layman could suspect a mammal and before long, recognize a dog, and finally, a spaniel.

Were we to adopt this individual, we should discover in due course, a combination of size, weights, proportions, colors, markings, habits and temperament, rare enough to require a special name. This name would not be included in any reliable work on taxonomy, but if our spaniel were sufficiently remarkable his name sooner or later would be inscribed in a stud-book. An important item in the specialized fancier's vocabulary would be our particular spaniel's name.

Although the specificities under consideration complicate our problem, in the long run, they are also the keys to understanding. If we would ask the geneticist just when our spaniel decided to be not like other spaniels, we should receive a clear-cut answer. He was not like other spaniels from the outset. Toward the end of

his unicellular career the act of fertilization added to his earlier endowment of maternal genes an equal complement of paternal genes. His maleness is traceable to a particular substitution of genes. These invisible units are protein in nature and within their forty-eight recognizable associations, orderly in array. Given the conditions under which a spaniel occurs at all, the genic endowment of this one, implied all the additional specifications needed to terminate in an individual classifiable by type yet too unique for domestication to go without his special name.

How the genetic proteins determine this end-result is momentarily not certain. Conceivably the genic master-pattern could undergo either extension or, like an ancient text handed down in many languages, appear in some form of free translation. These two suggestions are not alternatives. According to the estimates, the quantity of genetic proteins present at a given moment in the average human adult is sufficient to repeat the original endowment in the fertilized ovum, not less than $2.8 \times (10)^{13}$ times. Could all these repetitions be made contiguous, no doubt something accurately measurable in two dimensions and with special techniques in three, would become visible. Yet, until these or equally significant measurements become available, we can draw no precise picture of the genic pattern. All that we can be certain about, now, is that the organism and the developmental stages we see are not direct geometrical enlargements of that pattern. Whatever it is, it manifests itself during the life history of the individual only as a consecutive series of specific "translations." The members of this series differ in volume and shape, but each is implicit in the other and all, after the manner of stagger-patterns, determined by an original pattern or text. Accordingly, if, even direct topological identification of the genic pattern with its end-results or any of the stages intervening, is excluded, we can expect to find outward and visible signs of an inward pattern only if organisms at all times have properties invariant in all patterns and independent of all direct optical manifestations.

II

Specificities in minutiæ are conveniently explained by Mendelian mechanisms. Specificities in the gross illustrate the Biogenetic Law. Between the two types there is no type-difference. Both involve the genetic constitution and in the absence of growth with its inseparable context of simultaneous specific transformation, neither the small nor the large specificities could be recognized. In this association, items permanently isolated from their context become unintelligible. Yet, the nature of our problem forces us into the realm of abstraction. Ideally, we require a characteristic of growth that is also common to every pattern and at the same time faithful to the true nature of the organism. Here, we are confronted by a system of dilemmas quite hopeless were it not for the metrics of growth.

The attempt to describe every conceivable type of pattern reduces us to the level of a simple slogan: Whenever we have so much of this we also have so much of that. This statement like its formalized version, $y = bx^{\alpha}$ is a brief summary of all the work in allometrics. When x and y represent consistently any two dimensions of the entire organism, of its parts and organs, or of any two native chemical fractions, these quantities, if consistently paired over relatively wide reaches of size or age, exhibit fixed ratios. In the equation $y = bx^{\alpha}$, b represents the value of y when $x = 1$. The constant α asserts that a change in x of 1 percent is associated with a change in y of α percent. This relation is most conveniently stated in logarithmic form: $\log y = \alpha \log x + \log b$. In this form x and y are linear functions, (10: 22).

At the moment, the absolute values of x and y are not especially important. However, the value of α and particularly its behavior, have immediate significance. Alpha reflects not only the interrelations among the variables we have measured, but, also, how these measurements were used. Whether we compare a given kind of y with a certain type of x or do the opposite is unimportant, if we do not intend to make other comparisons. The two resultant α's are both constant and merely repeat so much of this for so much of that, antiphonally. However, when we wish

to compare our first α with the α's derived from other sets of x's and y's, it becomes highly confusing if the relations between our first standard and its comparate are stated in one way and those of the second pair in the other. Worse still, the kinetic relations of x and y in one set of pairs can hardly be identical with the same relations in all other sets of pairs. In the literature on allometrics (5) almost everything has been compared with almost everything else, in almost every conceivable way. Yet, despite these ineptitudes the organism continues to assert its coherent nature. A random sample of 275 α-values fluctuates about unity. Twenty-five percent of these differ from unity by 5% or less and in 11% of the cases, $\alpha = 1.00$.

Apparently the organism is not a hiding place for irrelevancies. If this appraisal is correct, items whose relationship to one another in a given organism is immediately clear, should yield α's more highly concentrated about unity and more frequently equal to one. Various dimensions of the growing chick and of its growing heart demonstrate the point (1). It can be demonstrated also over a wide range of organisms if we limit ourselves to significant index substances such as water and the chlorides or phosphorus, creatine, creatinine, and purine. All these, in various combinations, yield α's close to or equal to, unity. These cases are only a partial exhibit of the system of interrelationships named by Needham: "the ground plan of animal growth," (22).

Setting apart all specificities, even those of size and age, critical allometry uncovers among the structures and processes of the organism specific metrical relations. If one of the variables in this system changes by one percent, certain others also change by one per cent. Relations of this type are called isogonous. Were they the only ones, a spherical spaniel's egg could grow only into a large spaniel sphere. Alpha cannot always be unity. On the other hand universal heterogony, even if conceivable, could result only in the unrestrained complexity that is chaos. Every normal growth must have its isogonic core. This includes all the processes and items whose adjustment to one another must remain constant, within exceedingly narrow limits. As the organism

successfully domineers over the rigors of development and increasingly struts its dramatic diversifications, the isogonic underpinnings become obscured by their heterogonic canopy. Yet, even within the substance of the canopy itself, rates heterogonic with reference to the core are, or become, isogonic with reference to each other. Thus, all the α values for a given organism ultimately fall within a narrow zone. But, whether the relations they disclose in certain phases are 1 to 1, 2 to 1, or 3 to 1, α, in the end, always tells us how much of this goes with how much of that. Unless we insist on purely optical criteria, these metrical interrelations are more than symptoms of pattern. They are pattern in their own right.

III

Every pattern in a growing organism is at once a symptom and a herald. As a symptom, it becomes inexplicable without precursors, and if not a herald, it spells the cessation of development. If we desire insight into the processes by which precursors translate themselves into their own symptoms, which, in turn, are ultimately recognized as heralds when further specific transformations follow, the processes in question must be studied while they are going on. This calls for accurate timing. If we wish to study the growth of chickens, we cannot call the day of hatching, zero. This practice, still defended in other connections (10) omits the whole of incubation time. However, had the preceding 21 days counted as nothing, the chick would not be available to be misunderstood. Necessarily, when we make our observations, we must know the correct time.

We must also be serious about other things. We must choose periods of growth free from external interferences and protect our measurements against contaminations traceable to novelties internal in origin. We must always measure or weigh the same systems or items and distinguish between a natural fact and an analytical artifact. Success with individual items and constellations of these, depends on the sensitivity of our physical and chemical methods and on how we use them. Constellations

that cannot or should not be taken apart can be dealt with as entireties provided their constituents maintain constant proportions and have orders of magnitude large enough to completely swamp any minor contaminations. No one determining the total weight of a growing chick could possibly recognize the fraction due to the copper that is present. On the other hand, were the copper determined as a natural or artificial associate in another metallic isolate, equally rare or rarer, its presence in this complex would make an important and recognizable difference.

Under these critical conditions, adequate temporal analysis of growth in the entire organism, its organs, parts, or native chemical fractions, discloses in all of them increments stamped with the family likeness of compound interest. Yet there are important differences. The compounding occurs not at fixed intervals of time, but continuously. Moreover, the rate of interest falls. All this enables us to formulate a second slogan: More makes more, less and less.

In our second slogan, "less and less," implies an acceleration. Saddled with this, no organism can produce a constant percentage of itself during any two consecutive constant intervals of time. Were we to demand this, the organism could comply only if we were willing to make the second interval longer than the first. However, every type of chronometer we employ has a scale which divides time into a series of arbitrary units numbered consecutively from zero up, and equally spaced. The numerical value of intervals on these scales is the difference between two consecutive whole numbers, and is always unity. When we add all the units between a given point and the zero, the sum equals the total time that has elapsed since it was zero o'clock.

What the organism asks for is a new scale. Some of the advantages of the old can be preserved if the new scale coincides with the old at zero time and has the same number of intervals. Each interval, however, must be longer than its predecessor. If we are to pass freely from one scale to the other, such stretching of the intervals should be systematic and for all intervals proportional to their distance from the zero point. If an interval on the

old scale is definable as the difference between two consecutive whole numbers, all requirements will be met by the new chronometer if we define an interval as the difference between some power of consecutive whole numbers. By inspection, the power required is found to be two.

No available chronometer incorporates this principle. However, since we can pass freely from one scale to the other, old-scale readings can be treated as if we had used the new scale. By the old scale, the productivity of the chick goes down as the amount of time that has elapsed since the zero hour goes up. Hence, if the data derived from the chick itself are to remain inviolate we must employ, not the differences between the squares of whole numbers, but the reciprocals of these. The temporal datum we require for each interval is $1/(2t+1)^2-(t)^2=1/2t+1$. With the aid of this expression and a little calculus the relation between time and the growing weight of the chick, w, can be formalized. In logarithmic version it reduces to $\log w=k \log (2t+1)+C$ (5). This is the translation of our second slogan into the language of mathematics. It has the following implications. At a given new-scalar time, $2t+1$ old-scalar units from the zero point, the total weight of the chick is the product of its initial weight, C, compounded continuously at a rate that falls by a constant fraction k, of the intervals between the squares of the time units that have elapsed since growth began.

If our temporal analysis is faithful to the data, it should be possible to calculate not only what a chick of given age may be expected to weigh, but how much of a particular material it is likely to contain. For the chick as an entirety, it is possible to calculate weights from ages with fair accuracy in all cases and with complete satisfaction in some, (cp. Lerner; 12). This is essentially true also of the chlorides. In every organism, these are related by constant proportions and hence can be manipulated as a unit. When they are so treated, it becomes possible to calculate the average amount of Ca taken by the allantois from the shell. The orders of magnitude determined by chemical analysis and the orders based on the equation are identical. Even better agree-

ment is to be found in the case of water. Here, observation and the products of the equation are such that one set of values, plotted against the other, distributes the points on or along a straight line whose slope of 45° demonstrates a 1 to 1 relation between the two sets of values. Better yet, we can relate temporal with allometric analysis. From the latter, we learn that the percentage changes in y are α times the percentual changes in x. In temporal analysis the percentage changes in x and y are respectively k_x and k_y times the percentual changes in $2t+1$. It follows that the ratio $k_x/k_y=\alpha$. Accordingly, every conceivable ratio among the k values, established for the chick and a dozen entities, categories, and processes of the chick, should fluctuate about unity, while ratios based on data having the closest biological connexity, should be unity. Since these expectations materialize (5; 8) we have a bridge from allometry to the metrics of true growth.

IV

What other implications has $2t+1$? While the organism is growing, processes of two types go on at the cellular level. First, the total number of cells increases; and, second, an ever increasing number of these cells undergoes structural differentiations that incapacitate them for further mitoses (25). In the terminal adult, tissues, in which replacements occur, are normally the only sites where cell multiplication can be found. All cells, whether they continue to divide or not, ultimately contain the same genetic proteins in equal quantities. Clearly, however, the rate at which new genetic proteins can be housed in new nuclei declines.

As the most easily available index substance, we select purine nitrogen. According to our analysis, k for purine nitrogen and k for the chick are identical. Alpha, therefore, is unity. This value is exactly what we should expect for it is hard to imagine how a chick could grow normally at any rate other than the one characteristic of its genetic proteins.

We single out these proteins not because they are necessarily different from others, but because many pertinent facts are known about them which are not known about other proteins. We know

that they are present in chromosomes whose behavior in the sex cells leads to predictions that are quantitatively verifiable. Long ago (24), geneticists began to map the chromosomes indirectly with the aid of evidence obtained from adult fruit flies. Today, the giant chromosomes in these organisms are photographed. The photographs exhibit cross striations in orderly array. These bands, like spectral lines, are identifiable by their locations and many of them have been numbered. Between the chromosome photographs and the indirect genetic maps, as well as between either of these and the occurrence of specific traits in the adult, 1 to 1 relationships are demonstrable. It is fairly certain that we know where particular genes or gene complexes are located. These maps are patterns, not of the genetic proteins or even genes, but only of their distribution. Are the genetic proteins themselves patterned? This question cannot be answered directly. However, if they are patterned, which is not a new issue (4), and if they are also not categorically different from other proteins, all native proteins wherever or however located should exhibit at least some of the fundamental properties of pattern.

Every pattern is a matter of repetition. It is not for that reason inevitably monotone. It may be self-limiting or limited in space by the conditions under which it occurs. In either case, it can be repeated, extended, or repaired only if the various units whose arrangement compose it are all available in sufficient numbers. When this is true, the pattern itself determines how many examples of a given type of unit can fit into the limited number of specific complementary locations. Once these are occupied, all units that remain unaccommodated become useless with reference to this particular bit of pattern.

All this applies to any pattern, but it is also a generalized blue print for protein metabolism. We can refer to only a few of the elementary data. Growth is checked by the absence of lysine; repair, by the absence of tyrosine. No organism permanently harbors amino-acids except in the specific localities available in its native structural proteins. The units that are not so accommodated are destroyed and furnish the nitrogen in uric acid or

urea. No matter how much the nitrogen income may exceed the actual requirements, the organism remains in nitrogen balance.

Most of this knowledge is based on adults. During its growing phases the organism not only maintains what it has grown, but continues to grow. Its nitrogen income, therefore, must be relatively greater than in the stabilized adult. Nevertheless, as Schoenheimer (23) has so beautifully shown, the difference between the protein metabolism of a growing and an adult individual is not one of principle. It depends essentially on a shift in equilibrium. In the young, the sum total of synthetic processes exceeds the destructive. In the adult, synthesis, though very lively, is cancelled by destruction. Even greater significance attaches to Schoenheimer's results with isotopic ammonia. In birds, the nitrogen, so marked, registers in the purines and, also, in the uric acid. The genetic proteins, therefore, can no longer be considered as if they were completely isolated from the general metabolic stream. Like other proteins, they, too, are involved in both synthesis and destruction.

For the growing chick the absolute quantities of purine nitrogen and of uric acid (21; 5) together with their rates of accumulation, are all known. Very little arithmetic is required to show that if all the nitrogen in the uric acid were derived exclusively from the purines, the chick would be either without any genetic proteins or forced to produce double the quantity ever actually present. In this dilemma, our k values become decisive. K for uric acid is of the order 3.96, whereas, for the chick $k = 3.76$, and for purine nitrogen, 3.77. As the total nitrogen bound in uric acid equals the total bound in purine, since k for uric acid is larger than k for purine, and, finally, since the rate of purine synthesis could hardly be doubled without also doubling the growth rate of the chick, only one conclusion can be drawn. The nitrogen in the uric acid must have other sources. It cannot be attributed exclusively to the genetic proteins.

With protein metabolism of the embryo and adult in accord, we can take the next step. In the organism, between the hazard of destruction and the opportunity of incorporation, every popula-

tion of drifting amino-acid units always disappears. Both influences may be at work simultaneously. Ceaseless deaminization, regardless of amino-acid type, reduces the population by a large fraction without changing (except by chance) the ratios or proportions of the various amino-types. The non-nitrogenous remnants of the disrupted individuals are salvaged, yet, whatever their subsequent forms and fates, these are controlled in the last analysis by associations of units that have not been destroyed. When these are finally "on the track" to survival, their departure from the floating population involves the quintessence of specificity. Only units of given specific types locate in or on certain of the native proteins, provided these have niches specifically complementary to the incoming units. Of all the individuals ever present in the floating populations, the settlers are the only ones that count. It is, also, they that decisively influence our measurements. Even the local specificities of quality or order of magnitude that beset the organism stand in some proportionate relation to the qualities and quantities of specific proteins. Everything the organism is, has, or does, may be traced at long last to its protein machinery. It may work in ways that are dark and peculiar, yet its operations reverberate throughout the entirety (6; 7). If, despite local specificities, this influence is all-pervasive, the only dimension in which the proteins could always leave an easily legible signature is the temporal dimension.

When we determine a growth rate, our balances record, to date, the net total effect on weight, exerted directly and otherwise by all of the protein settlers. Toward the end of incubation, these represent 10 per cent of the chick's total weight and 57 per cent of its dry substance. Our clock-records should tell us not only how much time has elapsed since active protein settlement began, but also how much longer it takes, on the average, to settle today than it did yesterday. Both pieces of information are given simultaneously by our $2t+1$ chronometer.

But $2t+1$ is the difference between the squares of two consecutive whole numbers. Can this have any bearing? Since our measurements can take account only of settlers, the number of

these equals the number of specific locations they come to occupy. We do not know what these numbers are, but we do know from elementary statistics what the chances are that a unit of specific type will occupy its complementary specific niche. These chances equal the product of the number of units multiplied by the number of niches. Since these numbers are equal, the product is their square. As an example (and only as an example) with 10 specific protein niches and 10 complementary protein units available, the chances that a unit will settle can be rated at 100. If one niche has been occupied, the chances of the remaining nine, that are still bombarding the same total area, will be 9 x 9 or 81. After the second occupation, the chances for the third will be 8 x 8 or 64. Each niche that has been occupied, by virtue of that fact, reduces the chances of the remainder. Since the chances decrease by steps equal to the intervals between the squares of whole numbers, the time necessary for the process of settling should increase by corresponding increments. Our clock with constant intervals should register a declining rate of growth. Our $2t+1$-clock with its elastic shrinking intervals, should register a constant growth rate. Under conditions that have been carefully stipulated, this is precisely what happens. Thus $2t+1$, instead of being an anomaly, is a literal translation into the temporal dimension of the distinctive pattern of protein metabolism.

V

The one to one relation between tenant units and locations to be tenanted, by implication, foreshadows a geometry of growth. By definition, implicitly and explicitly, the organism is a unit. While the manifold of complex organic forms cannot easily be confined within the area covered by topological definitions, units that are not figures of speech have certain invariant properties in common. It is these that must be our subject matter. Accordingly, our geometry of growth will become no less abstract than the metrical system that is its foundation.

First and foremost are the relations of a unit entity to the space it occupies. Within this space no space is wasted. Densi-

ties in the organism, of course, differ. In the mouth are the teeth, saliva, and air. The air is continuous with the gases in the frontal sinus and antrum. In the coelom, are the "soft parts," some fluid, and some gases. In the cavities of the circulatory system, is blood. Elsewhere, we find lymph, synovial or cerebro-spinal fluid. Yet, no matter what densities we encounter, none of the spaces referred to could undergo changes in size or shape more serious than these borne by the more solid organs, without involving a complete reorganization and possibly the death of the entirety. Like the blastocoel of the invaginate gastrula, these spaces are essential internal working space. As such, it is one of the fractions whose summation is the unit organism in its spatial aspect.

In some of the spaces mentioned and in all the space not mentioned as yet, we find cells. These smaller units when not close-packed are imbedded in special substances of their own creation. These materials completely fill intercellular space and there play important roles. Cartilage and the other connectives, so-called, are good examples.

Among purely geometrical abstractions, the nearest relatives of our momentarily abstract organism, are the so-called space-fillers. Four, and only four types, are known: parallelopipeds like the cube; hexagonal prisms; rhomboidal and rhombo-hexagonal dodecahedra; and, the truncated octohedron or hexoctahedron. No matter how small the dimensions of these units, a sufficiently large number of anyone of them can fill any space however large—and fill it without interstices or vacant spaces. Since all space can be occupied by any of these systems, it follows that one system can be substituted for the other. Substitutions are also possible when fractional space is filled, for the properties of space fillers depend on shape and not size. Accordingly, the fraction of space occupied by one system of fillers can be occupied by any other system of space fillers with any desired degree of accuracy, provided we choose our units small enough.

In transforming our abstract organism into a system of space-fillers, we are free to exercise certain preferences. We can choose

any form we like, but, once having chosen, we are at the mercy of that form. For our purposes, it is desirable to combine maximal complexity with the highest biological probability. This narrows us down to the hexoctahedron, known also as the cubo-octahedron or truncated cube or more widely as the tetrakaidecahedron.

The conditions under which this form materializes in nature are two-fold. Among other instances, it is found as crystals in phosphotungstic acid. (3). Theoretically, it should appear in any system whose units are ideally quantified, of proper consistency, and under adequate and uniform compression. As Kelvin (11) demonstrated, the hexoctahedron divides space with minimal partitional area. In carefully constructed foams, it is more closely approximated than any other. This is also true in many plant and animal tissues (13–16), although the ideal form is rarely realized. In heart-muscle, it is not even approximated. On the other hand, no muscle, fibrous tendon, or neural tissue is known to contain waste space. For this reason, a system of this type can be transformed quantitatively into an ideal system. The approximate systems, such as the yolk of hard-boiled eggs where the ideal form is rare but sometimes identifiable (8), are self-compensatory, and hence can be treated as if they were ideal. This is true likewise in systems of starch grains. In corn starch, the form is present either as visible units or aggregates.

At one point in the natural history of proteins, these demonstrably constitute either a self-compensatory system or else have the form of a space-filler. Half of the genetic proteins of the individual are paternal in origin. During the act of fertilization, this half is contributed by the sperm-head. From the available measurements, one of the most eminent geneticists, Muller (20), has calculated that the total volume of the sperm-heads required to produce two billion human beings equals the space occupied by half an aspirin tablet. Under these conditions, the genetic proteins in the sperm-head would appear to be slightly crowded. If they are so crowded, they are present either as a system of irregular entities self-compensatory with respect to space, or else, as units, which have the shape of aggregates of space fillers.

When we examine the genetic proteins of caterpillars infected with the virus of flacherie, all the chromatin in certain nuclei has apparently disappeared. In its stead, we find the well known "polyhedral bodies" varying in size from 0.5 to 15 microns (9). Careful optical analysis of their forms discloses the square and hexagonal aspects and the angular measurements that identify the hexoctahedron as a unit and as a symmetrical aggregate.

Model stacks, in which the individual is the unit, are symmetrical, completely self-determining, and transform into rhombic dodecahedra. The surfaces of these are orderly terraces with nests of highly specific kinds, into which units of the next shell can fit in only one way. Although there are only twelve major planes, the dodecahedron has eight hexagonal aspects and six that are square. Face-centered on each aspect is a projection of the corresponding facet of the central unit. Here are all the connexities required for tight spatial organization. It is interesting in this connection, that the 8 hexagonal and 6 square facets of the basic space filler and the corresponding projections of these are topologically identical with the cyclol cage structures postulated for active proteins, (26, 27).

When aggregates of fifteen individuals are stacked as units, the original hexoctahedral form is restored when fourteen of these aggregates have been connected. Four more transform this object into an octahedron. In these super-aggregates, the terracing is accentuated and the nests, more numerous and varied, are larger and deeper than in those in which the individual hexoctahedron is the building unit. Such radical transformations and similitudes, together with the new diversities that appear, increase the biological relevance of the original form. It is a matter of considerable interest that some evidence of terracing is now available in the polyhedral bodies of insects and that super-aggregates of the hexoctahedral units, which retain the symmetries of the unit, e.g., these super-aggregates of fifteen composite units, conform to the specifications required by the data on bushy stunt virus (2). This virus appears in the form of rhombic dodecahedra.

Thus, the picture of aggregation, whether of individual units or aggregates, has a resemblance to Wrinch's idea that the heavier proteins, including particularly the viruses, are cage colonies composed of cage structures in orderly association (28, 29). This convergence of two lines of thought should not obscure the fact that these lines trace to totally different sources.

The metrical parameters of these aggregates have a peculiar fascination. Marvin (16) was the first to publish the aggregation series in terms of individual units. The equation describing this series is easily converted into the form of the $2t+1$ growth equation (5: 8). The quantitative data on hexoctahedral aggregation can therefore be substituted for either x or y in the allometric equation $y=bx^{\alpha}$. When shell number in the aggregate agrees with interval number on the time scale, then the predicted linear relation on a logarithmic grid is verifiable remarkably well for the chick as a whole, and for its chloride complex. (8). Equally good agreement may be possible with other aggregation series, but none would be accompanied by geometrical transformations or diversifications having the significance of this one. Moreover, none of the others are equally convenient. These particular aggregates simulate the $2t+1$ law in easily recognizable form. On the surfaces of 1-, 2-, and 3-shell aggregates, the units are arranged in terraced rows. The 1-shell aggregate has three such rows; the 2-shell aggregate has five, and the 3-shell aggregate, seven. Thus, the metrical system in which these aggregates enlarge is immediately manifest. This system based on differences in the squares of whole numbers was first detected in data on the growth of the chick as an entirety (5), but it can receive universal application. If our last step is correct, the $2t+1$ law is a consequence of protein metabolism.

That hexoctahedral aggregation should simulate an organic growth rate and, that the hexoctahedron as an individual and in aggregates should reproduce forms present or approximated at the cellular level and at subcellular levels in substances as different as corn starch, the bushy stunt virus and the genetic proteins of insects, can mean only one thing. All the processes concerned in

the growth of an organism have a common geometrical basis. In final detail, the geometrical and purely metrical pattern, as understood at this moment, will call for particular amendments. Nevertheless, the amended version is not likely to escape from the numerical parameters of this one, because this one has the numerical parameters of the organism.

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SECTION OF ANTHROPOLOGY

OCTOBER 27, 1941

DOCTOR FRANZ WEIDENREICH, Cenozoic Research Laboratory, Peiping Union Medical College, Peiping, China: *The Site and the Technique of the Excavations of Fossil Man in Choukoutien, China.** (This lecture was illustrated by motion pictures and lantern slides.)

Choukoutien, where the Peking Man—*Sinanthropus pekinensis*—has been recovered, is a typical Chinese village situated at the foot of the Western Hills (Hsi Shan) on the border of the Hopei plain and a little more than forty kilometers south-west of Peiping. The place had already acquired a certain reputation before it was recognized as the burial place of *Sinanthropus*. This reputation had really some connection with fossil man, for it is from Choukoutien that lime and coal are brought to Peiping. The lime derives from limestone quarries above Choukoutien, where it is burned in rather old-fashioned kilns, while the coal is mined, near by, in a not less primitive way. Thus, there are two Choukoutiens, a white one and a black one, both exactly corresponding to the two geological formations characteristic of the Choukoutien area.

The Western Hills represent the eastern margin of a deeply dissected Late Mesozoic platform with altitudes up to 3,000 feet above sea level. Geologically, their mass chiefly includes Ordovician limestone, Triassic sandstone and Jurassic conglomerates, slates, and sandstones. The high mountainous background is formed by these Jurassic conglomerates and sandstones, while the foothills of Choukoutien contain coal in the carboniferous slates and limestone and caves in the Ordovician strata.

The mountain range and the foothills, which stretch from

*The geological, stratigraphical, paleontological and historical data are compiled from earlier publications. The reader is referred in particular to the publication of the Cenozoic Research Laboratory: "Fossil Man in China. The Choukoutien Cave deposits with a synopsis of our present knowledge of the Late Cenozoic in China," Geological Memoirs, Series A, Number 11. 1933.

north to south, are dissected at Choukoutien by a short and narrow valley with an usually dry river bed running from west to east. This river separates economically, but not geologically, the white and black Choukoutiens. The foothills, south of the river, provide lime and caves, those north of it, coal.

The Late Cenozoic deposits preserved in the Choukoutien area occur in three formations: (1) as a terrace of gravels high above the present river bed and possibly belonging to the Lower Pliocene; (2) as a sheet of dark red clays; (3) as a huge Loessic erosional fan belonging to the Upper Pleistocene.

The Ordovician limestone includes a system of pockets and fissures which in some places are of large extent in width and length. The pockets are entirely filled with sand, rolled boulders and gravels. They are not fossiliferous. The fissures contain more or less cemented deposits of red or yellow clay, breccia, etc., and, are very rich in fossils. There are also true caves, partly empty, showing, in part, walls covered with old stalactites and stalagmites. The empty caves were probably formed in Upper Pleistocene times or even at a more recent date.

The fossiliferous fissures are of special interest to the paleontologist. They become exposed when the limestone is quarried, and quarrying has apparently been practiced in Choukoutien since, perhaps, prehistoric times; for banks of waste lime as refuse of kilns occasionally form terrace-like layers above the plain and the river bed.

Sinanthropus owes his discovery, primarily, to the exposure of such a fossiliferous fissure by commercial exploitation of the Ordovician limestone and, secondarily, to the initiative of the Swedish mining engineer, Dr. Gunnar J. Andersson, who was hunting for fossil bones during and after the first World War, while in service of the Geological Survey of China. In the spring of 1918, Dr. Andersson visited the Choukoutien district. In one locality known as Chikushan (Bird's Bone Hill), there stood an isolated pillar enclosing a great number of bones of small birds and mammals. This pillar, evidently, represented the only remnant

of an originally much larger deposit, the surrounding limestone walls of which had been completely broken away.

In the summer of 1921, Dr. Andersson visited the Chikushan locality, again, accompanied this time by the paleontologist, Dr. Otto Zdanski, in the service of the Geological Institute of the University of Uppsala, and our late friend, Dr. Walter Granger, who was on his way to the Gobi expedition. Quarrymen called their attention to a deposit, near by, much larger and richer in fossils than the one first discovered. This deposit was situated north-west of the railroad station of Choukoutien and at the north side of the foothill of that mountainous section that arises immediately south of the Choukoutien river and west of the great plain or, in other words, just where the river reaches the plain. This deposit is now known as Locality I and is, so far, the only site where human bones come to light. At the time of its discovery, the deposit was partly exposed at the head of an abandoned quarry. Among the loose material fallen into the quarry from the face of the deposit, Dr. Andersson noticed fragments of white quartz, a mineral normally foreign to that locality, and, at once, recognized this occurrence as an indication of the presence of fossil man.

The deposit of Locality I is, by far, the largest and richest of the fossiliferous fissures in the Choukoutien area. Fifteen of them have been excavated. They yielded very interesting faunas, some older, some younger, than those of Locality I, but no human bones. During a long period of history, Locality I must have been largely empty and cave-like. Gradually, however, through weathering action, periodical roof collapses and accumulation of detritus, its great cavity was filled with clay, sand and hard brecciated travertine.

At the time when the regular excavation of Locality I began (1926), the extension of the deposit, so far as it had then been exposed, amounted to 175 m. in a west-east direction, to about 50 m. in breadth (north-south direction), and to approximately the same dimension in height. There is, of course, no possibility of estimating the original extension in the latter direction. When

the deposit was discovered, it was already exposed at its uppermost layers and did not reach to the summit of the hill. This summit was, and is still, capped by a layer of extremely hard stalagmitic travertine full of bones of bats and teeth of other mammals. The contents of this layer prove that what today appears as the cap of the hill was once the floor of a cave with bats living in it. The walls and roof of this cave apparently situated above Locality I have been carried off by natural events, long ago.

Thus, the original shape and extent of Locality I cannot yet be fully defined. Five regions can, however, be distinguished. (1) What is called the Main Deposit. This forms the central and most extensive part of the exposed beds. (2) The Lower Fissure, represented by a narrow cleft extending northwards from the Main Deposit. As it dissects the northern limestone wall in its entire height, it offered the easiest access to the deposit from the river side. (3) The Kotzetang Cave. This cave is a wide hole within the eastern mass of breccia, and obviously an artificial formation; except for the northern wall, which consists of the original limestone. A hard, cemented breccia forms its walls and roof. What has brought about the formation of the cave is unknown, but it seems the result of excavations made, perhaps, by prospectors searching for workable limestone. (4) The Eastern Slope. This is the face of the hill which inclines eastward toward the plain. The surface of which consists of the same breccia that constitutes the Main Deposit. (5) The "Upper Cave." Its entrance is on the north face of the hill high up and near the top. The cave represents a hole in the Loessic formation, its walls partly covered with old stalagmitic incrustations. Downward, however, the cave extends somewhat into the deposit proper of Locality I.

Before describing the history and technique of the excavations at Locality I, some words may be said of the geological period to which its fossiliferous deposits have to be attributed. That they are Late Cenozoic has been already mentioned. To define the age more precisely, the stratigraphical facts, as well as the fauna recovered, indicate that the deposits fit in between the Late

Pliocene, at one extreme, and Upper Pleistocene, at the other. Consequently, they must be considered broadly as of Lower Pleistocene Age. More accurately, they are younger than the red clay formation at the third sedimentary cycle in North China which is characteristic of the Sanmenian, or, Late Pliocene period, but older than the Chinese Loess and the Mongolian sands which characterize the fifth sedimentary cycle of the Upper Pleistocene. Corresponding to this stratigraphic evidence, the fauna is determined by the absence of *Hipparion*, characteristic of the Late Pliocene strata in China, but at the same time, also, by the absence of *Bos primigenius* and red deer, both characteristic of the Upper Pleistocene strata. On the other hand, saber-toothed tiger, *Hyena sinensis*, *Rhinoceros mercki* and muskox, all found in most of the red clays of the Late Pliocene of China but absent in the Loess of the Upper Pleistocene, are still present in Choukoutien.

Excavations in Locality I were carried out first in the summer of 1921 by Dr. Otto Zdanski as paleontologist, and, again, in 1923. The fossil material collected then was shipped to Professor Wiman's laboratory in Uppsala, where it was prepared and studied. In 1923, Dr. Zdanski recovered a worn and fossilized molar tooth among this material and recognized it as human. A second tooth of the same kind was later found and, also, sent to Uppsala for preparation. When these discoveries were known in Peiping, the National Geological Survey of China, in cooperation with the Department of Anatomy at the Peiping Union Medical College and supported by a grant from The Rockefeller Foundation to the China Medical Board, organized a research program for an intensive and systematic investigation of the Choukoutien deposits.

Dr. Davidson Black became Acting Director of the Cenozoic Research Laboratory founded especially for this purpose, and the Swedish paleontologist, Dr. Birger Bohlin, took charge of the paleontological field work. In April, 1927, the work began in its new form. Three days before the spring excavations were stopped, because of the rainy season, an additional human molar tooth was recovered by Dr. Bohlin himself. The morphological character of this tooth induced Dr. Black to give the hominid

type so verified for Choukoutien the special name of "*Sinanthropus Pekinensis*," as suggested by the paleontologist of the National Peking University, Dr. Amadeus W. Grabau. During the following two years, several lower jaws, isolated teeth and a badly crushed parietal bone, were recovered. In December, 1929, just before the excavations had to be stopped on account of the approaching winter, Dr. W. C. Pei found an almost complete cranium of *Sinanthropus* (skull of Locus E) with only the face missing.

From their opening in 1927, the excavations went on, except for seasonal intermissions, up until the summer of 1937. Three days before the Japanese began the war with an attack near the Marco Polo Bridge, on the way between Peiping and Choukoutien, the work had been stopped, as is usual with the first days of July. On the very last working day, a well preserved fragment of an upper jaw and two isolated teeth of two more individuals were recovered. All the material stored up in the field headquarters in Choukoutien during the working season could still be safely brought to Peiping. In all these years since then, however, there has been no possibility of resuming the excavations.

The excavation of the "Upper Cave" was carried out in 1933 and 1934. It yielded an unimaginable wealth of skeletons of animals: hundreds and thousands of entire skeletons, or parts of them, of tiger, bear, deer, hyena, hare, etc., all belonging to the Upper Paleolithic. In addition, there were found, within a restricted area of the cave, skeletons of man with the morphological characteristics of modern mankind and, obviously, belonging to the category of Upper Paleolithic Man. Among the human bones were three well preserved skulls and fragments of four more, probably representing the remains of one family.*

The *Sinanthropus* bones and teeth recovered in Locality I,

*Recent literature on the "Upper Cave:"

Pei, W. C., The Upper Cave industry. Palaeontol. Sin., New Ser. D, No. 9, pp. 1–58, 1939.

Pie, W. C., The Upper Cave fauna of Choukoutien. Palaeontol. Sin., New Ser. C. No. 10, Whole Serv. No. 125, pp. 1–100, 1940.

Weidenreich, Franz, On the earliest representatives of modern mankind recovered on the soil of East Asia. Peking Natural Hist. Bulletin, 13. pp. 161–174, 1939.

during the period of ten years, belong to about 45 individuals, adults and children, males and females. They consist of 14 skulls and skull fragments, fragments of 14 diverse lower jaws, all of them belonging to individuals different from those represented by the skulls, 146 teeth in situ or isolated, 7 fragments of femur, 2 fragments of humerus, 1 wrist bone, 1 collar bone, and 1 fragment of an atlas. All the bones were broken and scattered over the whole deposit from top to bottom. Intermingled with these human remains, there were recovered thousands of animal bones, most of them fragments and broken in the same way as the human bones. There were, furthermore, collected thousands of stone implements, whole layers of seeds of hackberries, pieces of charcoal, layer of ashes, coprolites, in particular of hyena, burnt implements and burnt bones.

In order to collect and preserve all these manifold things and to determine eventually more closely existing relations between them, it was necessary to proceed with every possible care and, in particular, to mark in each case, the exact site where the finds had been picked up. To secure undisturbed and continuous execution of the work, the entire hill containing the deposits has been purchased for the Cenozoic Research Laboratory and a house was built on the premises with accommodation for the scientific staff of the laboratory when working in Choukoutien.

The excavations carried out by specially trained Chinese technicians are done chiefly with small picks and hooks. If the travertine blocks are too large, they are blasted with ordinary gun powder lest the explosion be too violent and rend the bone embedded within the matrix. In sandy, or loamy layers, only hooks are used. Every bone, bone fragment or tooth, however small, is picked up and put aside in a basket which each technician has ready for this purpose. A group of technicians always works together, so that practically each lump of earth will be scrutinized. Nevertheless, the loose earth, too, is afterwards transported to a special place and passed through a fine sieve. Blocks or hard breccia are cautiously broken into small pieces and, in case they contain bones, are also put aside in baskets.

In order to record the exact location of the finds within the large extent of the deposit, the excavating is carried out according to the following rules. First, the entire floor is leveled and then divided in squares drawn with white lines directly on the floor, the longitudinal ones running from west to east and the cross-lines from south to north. The lines keep a distance of one meter from each other, so that each square measures one square meter. The squares are designated by letters and numbers. The first series begins at the western border with the letter A, then follows the letter B, and so on. All the middle squares in the east-west direction have the number O; those south of them, the number +1, +2, etc.; and those north of them, the number −1, −2, etc. The excavating keeps strictly to these squares. Each group of technicians digs out the earth within four squares allotted to them down to a depth of one meter, while the partitions between the large squares, resulting from this procedure, are left intact as long as possible. All the material collected within one square is deposited in a basket, which carries letter and number of the square concerned. When the baskets are full, they are brought to the packers. The packers first protect the eventually exposed and broken bones with covers of plaster and rice paper, wrap each specimen in paper and write letter and number on the wrapping. Then the material is stored and shipped to Peiping from time to time.

A similar practice of designation is used to record the level the finds are coming from, that is, their locations in a vertical direction. The levels are designated by numbers and the lines marking them are painted in white on the surrounding walls together with the longitudinal division of the floor. The distance between two horizons is, also, one meter. Level number, together with the date of the recovery, is recorded on the wrapping of the specimens. In this way, it is possible to reconstruct by horizontal and vertical plans the exact locations of the finds.

At the end of the excavation season, the technicians prepare the recovered specimens in the main laboratory in Peiping. Bones

which have been recognized on the spot as human are sent immediately to Peiping.

As mentioned above, there has been no possibility of resuming the excavation work in Choukoutien since July, 1937, because of the political situation. Since several important finds were made the very last day we stopped the work, it is certain that we shall be successful when we may begin again. The extension of the deposit, still waiting for excavation, is approximately as large as the part already excavated. Of course, however, it is impossible to tell when the deposit will be exhausted. Nobody is able to make any prediction in this respect. As we know that there was once a cave on top of the hill, which has completely disappeared except for the bottom, it may be that we shall come across another cave, somewhere, below the one we are excavating now. There is still another possibility. The examination of the material derived from the travertine cap showed this deposit to be not younger than the main deposit, as was supposed, but evidently older and apparently belonging to Late Pliocene. This fact opens the prospect of possible finds within the area proper of Choukoutien belonging even to the Tertiary.

SECTION OF PSYCHOLOGY

October 20, 1941

Doctor Frank A. Beach, American Museum of Natural History: *Instinct and Intelligence.* (This lecture was illustrated by motion pictures and lantern slides.)

This evening, I am going to concern myself with the problem of the relationship between instinct and intelligence. I shall outline an hypothesis bearing upon this relationship, describe the line of reasoning which has given rise to the hypothesis, and report an experimental test of the validity of the hypothesis.

The Hypothesis

Our first step must be to outline the hypothesis which is to be put to experimental test.

Study of the behavior of many species of animals has revealed two facts of basic importance to the subject we are considering. The first fact is that members of the same species differ markedly in their intelligence in so far as intelligence is reflected in the available tests. The second fact is that individuals of the same species display great differences in the efficiency with which they execute complex patterns of instinctive behavior.

Differences in learning ability or intelligence may be illustrated by the range of error scores made by a number of rats tested in the same maze, by the differences in average length of time necessary for several monkeys to solve a problem, or by the differences in the I.Q.'s of human beings. Variations in instinctive behavior appear when we study the courtship, the mating behavior, or the maternal responses of many individuals in any one species. For example, some chimpanzee mothers with their first offspring appear bewildered and at a loss to know what to do with the infant. Other inexperienced mothers of the same species are much more efficient in the care of their young. Similar differences appear in more striking form in the case of the rat. A high

percentage of inexperienced female rats are able to care for their first litter quite as efficiently as an experienced mother. A few individuals, however, do not build a good nest before the arrival of the young, fail to clean the young as they are born, collect only a part of the litter in the nest, etc.

The hypothesis which I would like you to consider is this: Perhaps within a species the individual differences in intelligence are positively correlated with the individual differences in inherited behavior. It is possible that the efficiency with which an inherited response is executed depends in part upon the intelligence of the individual.

Development of the Hypothesis

Logical development of the subject leads us next to a consideration of several lines of evidence which seem to support the plausibility of this hypothesis.

Evolution of Behavior

Comparison of the behavior patterns displayed by animals at various levels of the phylogenetic scale indicates that, in the course of vertebrate evolution, three major changes have occurred in behavior. First of all, it may be observed that, in a general way, modifiability of behavior increases with evolutionary advancement. The simplest animals are not incapable of learning, but their ability to acquire new modes of response as a result of experience is distinctly limited in comparison to that of the higher living forms.

In the second place, it appears, on the whole, that the proportion of an animal's behavior repertoire dictated by inherited mechanisms is inversely related to the animal's position on the phylogenetic scale. Instinctive activities, forms of behavior rigidly controlled by inherited factors, comprise a very large part of the repertoire of lower forms. Study of the behavior of intermediate and higher groups reveals that less and less of the sum of the animal's potential reactions depend exclusively upon inherited organization.

Thirdly, it should be noted that such instinctive patterns as do persist throughout a large portion of the evolutionary scale become more and more flexible and modifiable as the phylogenetic position rises. In mammals, for example, certain patterns of response appear definitely to be inherited; but in each individual these reactions are subject to change and adaptation as a result of individual experience.

Evolution of the Brain

The significance of this evolutionary trend in behavior becomes apparent when we consider its relation to a concomitant series of changes in the brain. The evolution of the vertebrates has included acquisition and elaboration of new brain areas. Today, phylogenetic position is associated with the amount and complexity of the forebrain (*Illustrated by slide*).

The lower vertebrates possess small and relatively simple forebrains. Passage up the scale includes a rapid increase in the absolute and relative size of the forebrain. Finally, in the higher mammals, the cerebral cortex, which is the most recently acquired and complex portion of the forebrain, comprises 70 per cent of the entire central nervous system.

Theories of forebrain function

Observation of the two evolutionary trends which we have mentioned has led some students to suggest that the older parts of the brain control the older forms of behavior. That is to say, instinctive reactions depend exclusively upon the functioning of centers in the brain stem. This theory further states that the newer parts of the brain are concerned exclusively with modifiability and learning; or, the cortex functions only when the animal learns new responses through experience.

This line or reasoning receives support from experiments and clinical tests showing that removal or destruction of various regions and amounts of cortex is often followed by reduction in the ability to learn new reactions. For example, rats or monkeys or men deprived of varying amounts of cortical tissue are less able

to solve new problems than are normal individuals of the same species.

However, there is evidence (*Slides shown here*) indicating that destruction of cortical tissue also interferes with the execution of instinctive behavior. This fact may be illustrated by a motion picture comparing the maternal behavior of two female rats with their first litters. One animal is normal and the other has been deprived of approximately one-third of the cerebral cortex. (*A moving picture illustrating these rats was presented*).

We now have at hand several related facts. First, the evolutionary appearance of the cortex is associated with increased modifiability of behavior, learning ability or intelligence. Second, experiments with animals possessing a well developed cortex and, at the same time, retaining complex patterns of instinctive behavior have shown that the cortex is intimately concerned in the efficiency with which those inherited responses are carried out. Third, in these same animals, there exist marked individual differences in learning ability, and equally great variations in the efficiency of instinctive performance. These facts lead to the hypothesis presented at the beginning of my talk—namely, that, within a species, individual differences in the efficiency of instinctive behavior and individual differences in learning ability or intelligence are positively related.

Experimental Test of the Hypothesis Methods

In an attempt to determine whether there is any relationship between learning ability and efficiency in inherited behavior, a simple investigation was conducted. The experimental subjects were 40 virgin female rats without previous experience in learning tests.

Each animal was given 30 trials on a simple maze and the total number of errors was taken as an index to the individual's learning ability. Efficiency of inherited behavior was gauged by the results of a battery of maternal tests involving quantitative measures of the following activities: (1) amount and kind of nest-building before parturition, (2) care of the litter at time of de-

livery, and (3) retrieving of young scattered about the cage by the experimenter.

Results

Comparison of maze scores with records of maternal behavior revealed that those females which were the best learners on the maze made the highest scores on maternal tests, and those females that were very poor maze learners ranked among the less efficient mothers. Furthermore, a positive relationship between performance in the various tests of maternal behavior was revealed by the fact that females ranking above the average on one test (such as nest-building) tended to rank above the average on all other tests. (*These various interrelationships were illustrated by slides.*)

Conclusions

The positive correlation between maze learning and maternal performance is far from perfect, and it is probable that the relationship depends upon several factors in addition to those investigated in our study. Nevertheless, the results of this experiment appear to be in harmony with the hypothesis that the efficiency with which an inherited behavior pattern is executed is, in part, a function of the intelligence of the individual.

NEW MEMBERS

Added to the Rolls During the Summer Recess from April 24 to October 6, 1941

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